

The

EXCHANGER

Chemical and Biological Engineering

Spring 2015



Centennial

**A Historical Retrospective
of CHBE at UBC**

Grey Anatomy

Optimizing Solar Cells

**News, events, awards and
activities**



a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA



Message from the Department Head

The University of British Columbia will be marking its Centennial, from September 2015 to May 2016. The Centennial celebrates the anniversary of both the first class and of the first graduating class. It provides an opportunity to celebrate the many achievements of the past 100 years and to look to the bright future ahead. Chemical Engineering has been a part of UBC's extraordinary journey since the beginning. So I am particularly pleased to share with you the Spring 2015 issue of *The Exchanger*, which features a historical perspective of our Department at UBC. As usual, it is also full of stories about our students and faculty, our successes, awards, events and of course research, over the course of 2014. Our hope is that we can give you a glimpse of the exciting year we have just had.

The convocation in May each year is a chance for us to celebrate the success of our students and an opportunity to meet their families at the reception that follows here in our building. In 2014, our Department celebrated a number of new graduates receiving: 70 BAsC degrees (Chemical Engineering; Chemical & Biological Engineering); 4 MAsC degrees; 1 MSc degree; 9 MEng degrees; and 19 PhD degrees in Chemical and Biological Engineering. We warmly congratulate all these students and hope that we can remain connected and be a part of celebrating their future achievements.

Alumni visits to the Department are always a highlight of each year. The Chemical Engineering class of 1964 visited the Department in 2014.

This is a remarkable group of UBC chemical engineers who have remained closely connected in the 50 years since their graduation. The class of 1974 also visited us in 2014 and were delighted to be joined for lunch by three of their former professors.

This was a year of tremendous recognition for our faculty in winning important national and international awards for their excellence in scholarship and contributions to engineering. The year also brought some changes within our faculty. Dr. John Grace, P.Eng., joined UBC in 1979 as Head of the Department of Chemical Engineering. He retired in June 2014 following a distinguished career. The Department took the opportunity to organize an International Workshop on Fluidization in his honour. This was followed by a Reception celebrating his achievements and his contributions to the Department, to UBC and to the wider community in research, teaching and service. Dr. Vikram Yadav joined our Department as assistant professor in 2014. He is pursuing a fascinating line of research at the interface of chemical and biological engineering with medicine. Dr. Vladan Prodanovic, P.Eng., also joined us as a Senior Instructor jointly with the Department of Mechanical Engineering. He has a special interest in advancing Clean Energy and will be responsible for the Professional Masters Program in Clean Energy offered jointly with Mechanical Engineering at the Clean Energy Research Centre.

We hope that you will enjoy reading this latest issue of *The Exchanger*. We always look forward to hearing from you and would be delighted to welcome you to the Department.

Dr. Peter Englezos, P.Eng.
Head
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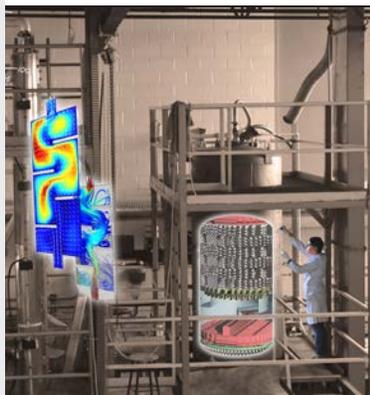
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On the cover

The cover design was based on a photograph in the CERC High Head Lab by Ehsan Oveisi of Fahimeh Yazdanpanah, both Chemical & Biological Engineering PhD students.

Graphic by Vikramaditya Yadav.

Grey Anatomy

Biological Engineering & the fight against neurodegenerative diseases

I have a candid confession to make. I penned this essay in the immediate aftermath of Super Bowl XLIX. Should the Seattle Seahawks have run the ball rather than pass it? Every armchair expert has an opinion and the game's exhilarating ending will be discussed for years to come. Yet, lost in the endless hours of post-game analyses was the realization that Julian Edelman, one of New England's stars on the day, may have suffered a grievous concussion during the very same play that kick-started his team's come-from-behind victory. Edelman's clash of heads with Seattle's Kam Chancellor was indescribably violent and he staggered to the ground shortly after. However, instead of withdrawing the stricken player from the game for medical assessments, New England controversially soldiered on with him. That Edelman would go on to make the game-winning catch in the final minutes of the game merely adds to the intrigue of this sub-plot.

The Edelman incident brought the NFL's weak stance on chronic traumatic brain injury sharply into focus. However, New England's decision to continue playing with a concussed player was not an anomaly. In fact, statistics for the 2012 and 2013 seasons suggest that over 50% of players with a concussion never missed any games. Courageous as it might seem, these players are at grave risk of long-term neurodegeneration. Repeated concussions lead to the accumulation of clumps of abnormal proteins called tau in the frontal and temporal lobes of the brain that, over time, take a deadly toll on nerve cells. Interestingly, this pathophysiology is exactly similar to another trauma-induced neurodegenerative condition called chronic traumatic encephalopathy (CTE), as well as an inherited brain disorder called frontotemporal degeneration (FTD). CTE and FTD together account for the highest number of dementia cases in people under the age of 65, and both diseases incur high caregiver costs and significantly diminish economic output. Treating these debilitating diseases is therefore an urgent medical priority. Unfortunately, though, there are no known treatments for CTE, FTD or any other neurodegenerative condition.

Presently in the pharmaceutical industry, pre-clinical testing of lead compounds commences with an assessment of their activities using cortical nerve cell cultures. Although this process sounds straightforward, it is anything but. Maintenance of cortical nerve cell cultures is extremely challenging, and reliable operating procedures were only established very recently. Furthermore, cortical cell cultures do not incorporate key constituent tissues of the human brain such as the blood-brain barrier. As a consequence, diffusion of the lead compounds across the blood-brain barrier, which has long been the Achilles heel of drugs targeting brain tissue, is never actually evaluated until the molecules are tested in patients – a potentially calamitous scenario. Regulations stipulate that lead compounds exhibiting positive activity in cortical cell cultures must then be tested in whole animal models, preferably those that bear anatomical traits that are similar to humans. The greater the degree of similarity between the target organs in the animal model and human patients, the more insightful is the testing. Unfortunately, though, the best neurodegeneration animal model the pharmaceutical industry has at its disposal is that of the rodent. Unsurprisingly, results from pre-clinical animal testing do not translate well to the clinic, and nearly all drug candidates targeting neurodegeneration fail when tested in real patients on account of poor safety and/or efficacy.

To this end, an ambitious collaboration between the Department of Chemical & Biological Engineering and the Faculty of Pharmaceutical Sciences at the University of British Columbia that is currently afoot could provide a much-needed shot in the arm for the discovery of anti-neurodegeneration drugs. Our research team comprises Dr. James Feng, P.Eng., and me from CHBE and Dr. Urs Hafeli and Dr. Ujendra Kumar from Pharmaceutical Sciences.

We are applying micro-manufacturing, stem cell engineering and mathematical modeling to design and assemble a brain-on-chip device that mimics the human brain. A brain-on-chip is a type of organ-on-chip device, the kinds of which have already attracted the attention of the pharmaceutical industry. Organ-on-chips are miniaturised, three-dimensional models of human tissue that recapitulate the spatiotemporal complexities of the tissue microenvironment as they occur within the body. This provides a highly context-specific platform to test and validate lead compounds, which improves the success rate of compounds in the clinic. We will subsequently utilize this device to investigate fundamental details about neurotransmission and test lead compounds CTE and FTD in a high-throughput manner. Our team combines an eclectic mix of specializations in biology, chemistry, engineering, radiopharmaceuticals and neurotransmission, and the combination of mathematical modeling and analysis with key concepts from stem cell bioengineering, micro-manufacturing and engineering design represents a methodological advancement that will potentially open new frontiers in biomedical engineering.

Dr. Vikramaditya G. Yadav



Optimizing Solar Cells

Despite Canada's position as a global energy superpower, the environmental repercussions of fossil fuel consumption will ultimately force our nation and the global community to make a dramatic shift towards carbon-neutral forms of energy. The sun holds the greatest potential as a sustainable energy source on the scale that is required, but less than 0.01% of Canada's energy mix is currently met through direct solar energy conversion. This shortcoming is a consequence of the high temperatures and vacuum conditions required for the fabrication of conventional solar cell materials—which render solar electricity five-fold more expensive than electricity produced from conventional resources (e.g., coal, hydro, nuclear)—and because cost effective methods for storing intermittent electricity produced from solar farms and wind turbines are lacking. Prof. Curtis P. Berlinguette (Canada Research Chair in Solar Energy Conversion and Alfred P. Sloan Research Foundation Fellow) is leading a program that is seeking methods to address these obstacles, in pursuit of an economically viable renewable energy economy. His research is centered on the design and fabrication of advanced solar cells that operate efficiently in urban environments, and convert electricity into hydrogen fuels more efficiently.

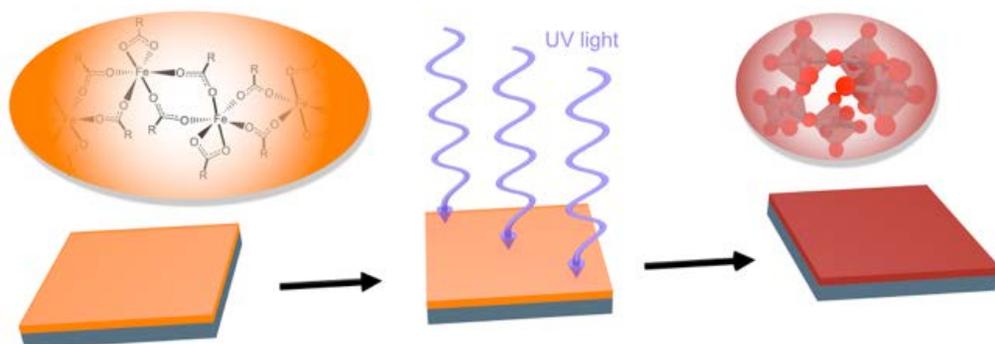
Conventional photovoltaic (PV) materials that convert sunlight into electric energy rely on semiconducting materials containing either high purity silicon or extremely rare metals such as cadmium and tellurium. The Berlinguette group is seeking ways to deploy solar cells that can be made with more sustainable fabrication techniques. The solar cells he is focused on, called dye-sensitized solar cells, require much less energy to make. Moreover, they operate very well at low light intensities compared to conventional technologies. This more efficient power production at lower light intensities makes them attractive not only for indoor applications, but also for urban installations that are subject to shadows from trees and neighbouring buildings. This technology is particularly attractive for cities like Vancouver that often have cloud cover because the cells can perform better than conventional technologies. These benefits notwithstanding, a key shortcoming to deploying this type of solar cell technology at scale is device stability. Many of the companies that are trying to commercialize these technologies are unable to guarantee performance over long time periods.

The Berlinguette group has capitalized on these technologies by focusing on how to sidestep the current weaknesses of the cells. They have devoted significant efforts to understanding how these cells break down, and have devised chemical strategies to addressing these specific shortcomings. A key breakthrough for the field that was discovered in their labs was identifying how the light-harvesting molecules typically used in these cells were breaking down. They then devised a platform that contained a completely different molecular manifold that yielded the exact same performance parameters, but offered a much more stable platform for use in the solar cell architecture. They have continued on with this effort to unravel some interesting photophysical phenomena with semiconductors that can be used to further enhance the performance of these devices.

A further aspect of Dr. Berlinguette's program is centered on making better electrocatalyst coatings for hydrogen generation; this has the additional benefit of being nicely aligned with the vibrant local economy in BC's lower mainland in fuel cells and electrolyzers. Dr. Berlinguette is interested in developing facile methods for making electrocatalysts that more efficiently convert electricity produced from solar cells into chemical fuels, such as hydrogen, that are easier to transport and store. While his program initially adopted the strategy of designing molecules to better understand the mechanistic aspects of each reaction step, he has since applied this knowledge to developing unique ways of making more commercially viable catalyst platforms. He recently reported, as part of a collaboration effort with Prof. Trudel at the University of Calgary, that shining UV light on photo-active paints could yield state-of-the-art electrocatalysts without ever raising the temperature of the substrate. A powerful attribute of this method is the unprecedented ability to introduce any metal desired into these films, while using very scalable techniques. The research group has recently extended the goal of developing soft and versatile synthetic methods by finding that a common heat lamp, such as would keep your hamburger warm at the local fast food joint, is enough to access many of these state-of-the-art materials.

Berlinguette is excited to find himself at UBC because of the core strengths in electrocatalysis research at CHBE and in the local industry, which is a global hub for clean energy technologies.

Dr. Curtis Berlinguette





CHBE at UBC

A Historical Retrospective

By Anne Marie Corrigan

Above: University of British Columbia Fairview campus on the site of Vancouver General Hospital, circa 1917, looking northeast.

From Little Acorns...

A pursuit of learning, cutting-edge research and desire for scientific advance in this critical field of applied sciences is the real story of the 100-year journey of the Chemical and Biological Engineering Department (CHBE) at UBC. But it's a long road and with a century under its belt, the path of this Department has taken many interesting twists and turns.

Like many great institutions, CHBE had humble origins in the Chemical Engineering program, which could not have started in a more modest fashion. In 1915 students were taught in a tent, "The Chemistry Tent", which was part of UBC's "Fairview Shacks". Both of these monikers were bestowed on what were UBC's first temporary rickety structures, situated close to Vancouver General Hospital.

The fledgling program's first years, at what was then called the McGill University College of British Columbia (later to become UBC), were impacted by the outbreak of "The Great War" when the potential student

body headed off to fight in Europe. The first and only chemical engineering student who graduated with a B.Sc in Applied Science in 1917 was Charles A. H. Wright. He proceeded to take an M.Sc. degree - again the first in an engineer-

ing program at UBC. He and another UBC chemical engineering student, B. P. Sutherland, were key figures in the production of heavy water (used in nuclear technology) in the later years of World War II. Wright went on to an illustrious career with what is now known as Teck Resources in Trail.

**First Female Student,
Rona Alexandra Hatt,
graduates in 1922.**

"We Need a New Shoe!"

Today, Chemical and Biological Engineering students are taught in the chrome and glass CHBE building on UBC's Point Grey campus with its wood panelling and lofty ceilings. To young minds the spit and polish of these halls is as much a part of their learning experi-

ence as knowing what to do with a pipette, but the path to these modern digs was gritty and arduous. The journey required a mobilization of youthful energy and creative persuasion techniques.

During the years after The Great War, enrolment in chemistry courses grew rapidly. The program attracted enthusiastic and high-calibre faculty members such as Dr. W. F. Seyer, the first long-term leader, who developed a new course entitled "Chemical Engineering". Chemical Engineering, as a teaching entity, was under the umbrella of Chemistry in the Faculty of Arts. With the influx of returning war veterans, the Chemistry Tent was bursting at the seams. Temporary and makeshift accommodations for lectures and laboratories were not enough. Something had to be done.

In 1908 the provincial government dedicated the grounds at Point Grey to the university. Work began on the Applied Science building in 1914 which was to house Chemical Engineering, but with the advent of The Great War and a lack of political momentum the work was very slow. UBC students decided to force the government's hand to finish the job and so the idea of The Great Trek was born.

On October 25, 1922, almost 1200 students gathered together in downtown Vancouver. A parade of colourful floats and young people bearing banners began wending its way through the streets of Vancouver. It continued along Blanca Street all the way to the verdant fields of Point Grey. Students carried signs that read "Point Grey or Bust!" and "We Need a New Shoe!". Once they arrived at the bleached bones of the unfinished skeletal structure of the Applied Sciences building they climbed into the hollow rooms. The pomp, pantomime, energy and determination of the students aroused attention and evoked an immediate government response to complete the construction of the new campus. The Chemistry Department was one of the first occupants of the Science building. It was the first permanent structure and home to chemical engineering, and remained so for almost four decades.

**University Fees
in 1919-20:
\$17 per annum.**

Peaks and Troughs

A fifth year was added to all engineering programs in 1929-30. A practical requirement was also added, whereby students gained hands-on experience by working one day a week in various industries in the Lower Mainland.

The arrival of World War II saw a dip in student numbers. Chemical engineering professors and students put their energy and resources into the war effort. Graduates were offered extra academic credit for working on projects related to war research. Many were employed in the war-time chemical industries that sprang up across Canada. A temporary structure was added to the Science building primarily to train air-force technicians.

With the end of World War II came a mushrooming of student numbers. Army huts were installed to house the flood of war veterans. Once again the need for new space became critical. In the summer of 1948 a temporary addition was erected at the back of the Chemistry building. A total of 65 students graduated from chemical engineering in the late 1940s. During this time, the students and curriculum were under the Dean of Applied Science while faculty members reported to the Dean of Arts and Science.

In the early 1950s Drs. Shemilt, Scott and Epstein advocated for separation from the Chemistry Department. They released their *Recommendations for Formation of a Department of Chemical Engineering*. It took three years for the document to work its way through the system. Finally, in 1954, the Department of Chemical Engineering was established within the Faculty of Applied Science. Throughout the fifties the chemical engineering faculty offices and unit operations lab were located in the basement of the southeast wing of the Chemistry Building, a primitive structure with cramped quarters, which once flooded as a result of a lab experiment.

Forceful intervention by Dr. Stuart Cavers and effective behind-the-scenes work by Dr. Shemilt resulted in the first Chemical Engineering building being constructed at a total cost of \$750,000.

An outside head of the Department, Dr. J.S. Forsyth, was appointed in 1957, despite vigorous petitioning by Drs. Epstein, Cavers and Scott to appoint Dr. Les Shemilt. With the arrival of the new head trouble began brewing. Following a string of petty spats with faculty and students alike, a petition was signed by students in 1969 stating that they no longer had confidence in Dr. Forsyth. He lost his position as head of the Department but stayed on as a professor. Dr. Frank Murray took over and calmed troubled waters. Camaraderie returned to the Department under his leadership. The sixties also saw the Department move into a new location which housed it from 1961 until 2006. The seventies saw anti-Vietnam war protests on campus,

boycotting of some chemical companies by students, teach-ins and peace marches. Research was booming, facilities were good, jobs plentiful and the students became highly successful leaders in industry.

Department Takes on Leading Role in Alternative Fuels Research

When Dr. John Grace, P.Eng., came to the Department as head in 1979, he found the place lacking in energy or "sleepy" as he describes it. The Department had a "hippy" reputation amongst the chemical engineering community. Things began to wake up when, thanks to federal government funding, the Department was able to channel its resources into alternative energy research. There was ground-breaking research into spouted beds, electrochemical processes, coal gasification, fluidization and fluid-particle research and solar energy applications. Efforts were doubled in researching water and air pollution control.

Expansion in the 1980s once again presented challenges for the Department which became painfully short of space. Every scintilla of floor and counter space was occupied. One office was called "The Kennels" due to its narrow and cramped quarters, and the building in general was a fire hazard. Despite recognition by the Senate Academic Building Needs Committee that construction was a necessity, nothing helpful was built for 25 years except for the Pulp and Paper Building which was finished in 1986. The undergraduate program switched to a four-year program and the Department of Agricultural Engineering changed its name to the Department of Bio-Resource Engineering. In 1996 the Chemical Engineering Department amalgamated with the Bio-Resource Engineering Department; later it became the first in North America to adopt the title of Chemical and Biological Engineering. Many other universities around the world have since followed suit.

In 1956, the first PhD program was offered in the Chemical Engineering Department. Courses in mass, momentum, heat transfer, unit operations, applied thermodynamics and kinetics were offered. The first PhD graduate was Dr. Francis Dullien.

Below: Peter Roberts, Chris Castle and John Baranowski in the Chemical Engineering Workshop, circa 1990's.



The Bell Tolls for CHBE

When Dr. Peter Englezos, P.Eng., current Head of the Department, joined the CHBE faculty in 1990 he was attracted to the collegiality of the Department. He found Dr. Ken Pinder, who was head at the time, to be an “outstanding individual in many ways” who emphasized the hands-on training of students and thus supported a strong laboratory focus of the curriculum. UBC was changing from a provincial to a world-class university. There was, however, a growing blister of worry. The facilities at the Chemical and Biological Engineering Department were confirmed to be sub-standard by the Canadian Engineering Accreditation Board and, as such, the Department’s accreditation was at risk. There was overcrowding and inadequate ventilation leading to potential safety hazards.

The promise of a \$23 million new facility was postponed due to a provincial freeze on capital funding. Parents and students alike were upset. Morale was low. Dr. Englezos remembers the time clearly.

“It was very stressful,” he says. “But the Department, the Dean of Faculty and the President of the University provided relief. Everyone pulled together. Extensive renovations to the tune of \$1 million were carried out to upgrade facilities and the fear of non-accreditation was allayed.”

There was also a drive to better equip students for the evolving job market. UBC Engineering Co-op offered work-terms to students to gain relevant hands-on experience. A new curriculum was also designed to train chemical engineers for the evolving biotechnology industry and the bio-economy. The new degree program in Chemical & Biological Engineering was accredited in 2003.

In 2001, the UBC Clean energy Research Centre (CERC) was established thanks to a \$9 million award given by the Canadian Foundation for Innovation. Three years later construction started on the 10,000 m² building and research facility that is used today.

Goodbye Mr. Chips. Hello Mr. Chip

Dr. Norman Epstein, P.Eng., who at 91 years of age is close to celebrating his own centennial, has been part of the CHBE faculty since 1951. He still comes in to the office every day and has lived through many changes. He wonders how students actually learn nowadays.

“We used to use blackboards, chalk and textbooks for teaching. Now there is Power Point and the students get notes handed out to them. Why do they even need a desk?” he muses.

“The learning process that I understood took place when I wrote on the blackboard and the students copied the

notes as I wrote. They would have time in that process to absorb information and mull over them at home. The action of me writing on the board and thinking aloud and the students taking notes, summarizing as they went along, is my understanding of the learning process. What do they do now?” he wonders.

Dr. Epstein will be glad to know that blackboards are still used, all these decades later. When it comes to the fundamentals, fourth-year chemical engineering student Collen Chau explains that some acquiring of information still occurs in the traditional “learning from the blackboard” way. However, both students and professors agree that the more modern development of hands-on learning shows a true advance in the teaching and training process. Colleen feels that all students do better when they are actively engaged.

“We appreciate learning the fundamentals in the old-fashioned way,” she insists. “However most of our learning comes from the hands-on experience that we get in labs or in clubs.” She is active in the Chem-E-Car Club where students make toy cars that start and stop, using chemical means. “We love it because we can apply all of our knowledge in making the cars. If we are stuck we ask professors or we can go on the internet which is an amazing learning tool.”

Dr. Englezos is aware of the importance of engaging students through real-life experiences.

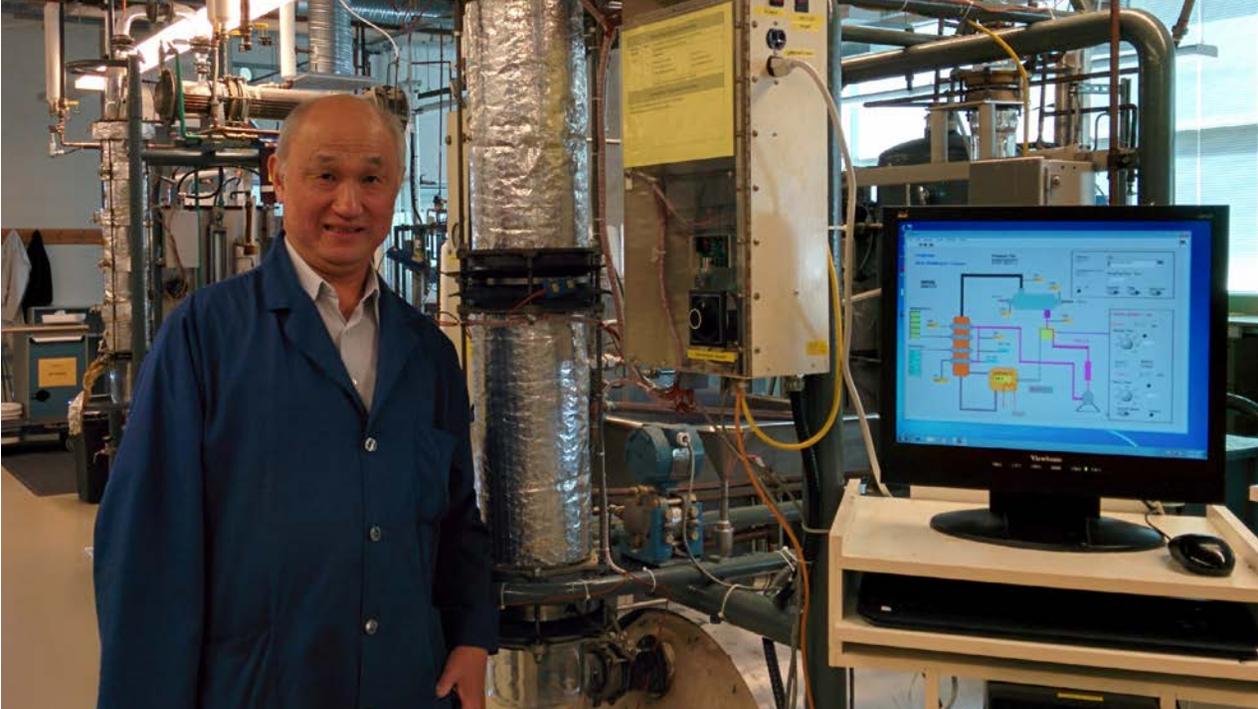
“Global trends and especially the advent of the internet created new challenges and opportunities in what and how we teach at the Department. Because content is more freely available, we are providing more hands-on experiences both inside and outside of the classroom. For example, we have a stronger Co-op program where students have more opportunities for professional development.”

There is also a student exchange program that CHBE is part of at UBC, that enables students to take courses at numerous top universities across the world at no extra tuition cost.

Dr. Epstein acknowledges that times have changed and therefore the needs of chemical engineering have changed since he began in the Department 64 years ago.

“Chemical engineers are more interested in the environment and sustainability now. Engineers realize that we cannot continue using oil forever. We must phase out the use of fossil fuels. There is a lot of work at the moment on finding ways to capture CO₂. We are trying to prevent it from getting into the atmosphere.”

Dr. Grace, who was recently conferred with the Order of Canada, agrees: “Personally I am very concerned about the oil sands. The students we have today are divided on environmental issues. Some have a great deal of concern about what is happening; others are more concerned about how successful they will be financially in the industry.”



Above: Alex Thng, Electrical Technician, checks a packed bed distillation column program in the Undergraduate Lab.

Below: Research Day in the Chemical and Biological Engineering Atrium.

All for One, One for all - Linking Hands Across Disciplines

Dr. Englezos has great faith in the future.

"Our discipline is strong. It has evolved with biology as its fourth pillar. We have a strong intellectual core and our discipline can work with others. We have very successful joint faculty appointments with Chemistry, Math, Mechanical and Mining Engineering and we hope to expand to Medicine and Forestry. With such hands linking across the disciplines we can make a real difference towards achieving a better quality of life through new and improved processes, products and services."

Nowadays, CHBE is a hive of exciting research and activity. It attracts the highest calibre of student and professor alike. One such professor is Dr Vikram Yadav - an energetic and highly-enthusiastic new addition to the faculty.

A great lover of the outdoors, Yadav always had his sights set on Vancouver. The beauty of the Lower Mainland coupled with a myriad of multi-disciplinary opportunities for research at CHBE attracted him to work here. The Michael Smith Laboratories, CERC, Life Sciences Centre, the research in genomics, drug research and development, the work in biomass conversion, bioprocess engineering, infectious disease pathogenesis, Green chemistry, medical biotechnology, metabolic engineering, synthetic biology and tissue engineering can all be explored within the Department.

Dr. Yadav enthuses about the stimulating research opportunities at UBC. His current exploration in finding a drug to cure Alzheimer's warrants a whole article in itself. He works with a team; one person an expert in mathematical modelling systems, another in neurotransmission and the functions of brain tissue, yet another in drug synthesis; Dr. Yadav is focusing on stem-cell engineering. His group

has built a model of a three-dimensional human brain which fits on a microscope slide. The structure consists of a layering of brain cells which mimic the functioning of the brain. Dr. Yadav injects drugs into this structure to try and reverse the disease. These four different groups bring four different perspectives to the problem and have made exciting strides in finding a possible path to treating Alzheimer's, thanks to their collaborative efforts. This is just one example of the stable of world leaders in academics and research at CHBE.

Dr. Englezos brings the successes of the past 100 years back to the students.

"Young people who are a part of CHBE come to the Department with a tremendous reservoir of goodwill to contribute to societal good. They have a strong commitment to protecting local and global environments for the greater good. We strive to ensure that we offer them a balanced, up-to-date curriculum and learning experience."

This Department's evolution has always had a love of learning at its core. Although the past century has brought changes to the physical location of chemical engineering at UBC, the great minds that have driven the changes have always been a constant. And even though the bricks and mortar of the Chemical and Biological Engineering Department have changed over this past century, it has always been a true "place of mind".





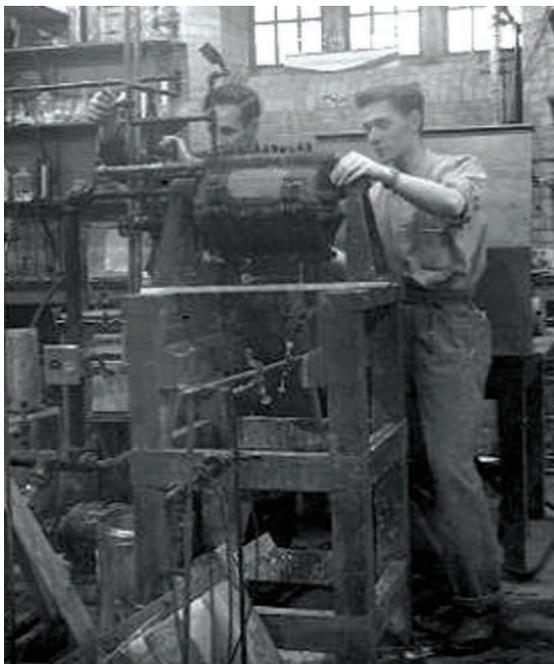
Above: Breaking ground for the new Chemical and Biological Engineering Building in 2004. Left to right, Bob Evans, A. Paul Watkinson, Michael Isaacson, Barry McBride, Kevin Smith and Stewart Blusson.

Below: Work in a Chemical Engineering Lab 1943.

Bats In the Belfry

Every family has a “crazy aunt” story and CHBE is no different. One story in particular stands out. It involves a con artist who attempted to befuddle the Department and medical community - a fascinating character who went by the name of Dr. Kurt Wallersteiner.

Dr. John Grace was Head of the Department when one day in 1980 he looked up from his desk and saw a tall, distinguished looking man standing in front of him.



“He was impeccably dressed and had an air of gravitas,” says Dr. Grace. Wallersteiner told Dr. Grace that during his doctoral studies in England in the 1940s he had inadvertently made interferon, which was hailed as a possible miracle drug for cancer. He claimed great financial success in the business world and now he wished to devote his time and energy to developing a commercial process for interferon.

“He told me that he just needed a small corner in one of our labs to work in and if he was successful that he would donate all proceeds to the University,” says Dr. Grace.

The Head checked with Assistant Head, Dr. Ken Pinder, to see if Wallersteiner’s knowledge was current. He also looked over the CV and references, which he found to be just about adequate. However, as time progressed, Dr. Grace’s ‘spidey senses’ started tingling. Discrepancies appeared in two CVs and personal contacts with the UK raised serious doubts about the authenticity of the visitor.

Finally Wallersteiner’s scam was rumbled when Terry Fox had to abandon his famous run across Canada after it was found that is cancer had returned. He came to Vancouver to try hopeful treatment with interferon. Wallersteiner was contacted by the medical community to help provide the miracle cure. Part of his proposed process to formulate the drug required a fleet of ambulances to converge on the Department bearing foreskins.

By now Dr. Grace was convinced that Wallersteiner was a fraud and sent him packing. Later he was shown a copy of the British satirical and current affairs magazine, *Private Eye*. In it was a story about Dr. Kurt Wallersteiner, who had not only defrauded the Bank of England out of millions of pounds but had also escaped from a prison in Frankfurt.

Dr. Vikramaditya G. Yadav

As a chemical engineering freshman at the University of Waterloo, Dr. Vikramaditya G. Yadav coveted a career in Alberta's burgeoning petrochemical sector. He even interned at Imperial Oil during his first summer break from university. Then, on a chilly Ontarian fall evening during his second year, he stumbled upon a copy of Juan Enríquez's *As the Future Catches You* in the library and became instantly captivated with biological engineering. His journey over the years has taken him to Sanofi Pasteur, where he worked on designing next-generation vaccine manufacturing processes; the Massachusetts Institute of Technology, where he received his doctoral degree for a thesis on engineering enzymes and bacteria for synthesis of pharmaceuticals; and, most recently, Harvard University, where he worked on biophysics

and biological thermodynamics. Now, as an Assistant Professor in the Department of Chemical & Biological Engineering at UBC, he is guiding a truly wonderful group of young researchers in one of the very best ecosystems for biotechnology and life science research in Canada to engineer biological systems for applications in energy, medicine and environmental remediation. His research group works on wide-ranging topics such as metagenomics, plant chemistry, tissue engineering, drug discovery, pharmaceutical manufacturing, and even Alzheimer's disease. Dr. Yadav also enjoys teaching and interacting with the student community at UBC, and rates the student body in the Department among the very best that he has experienced. To learn more about Dr. Yadav's work, please visit www.biofoundry.ca.



Dr. Vladan Prodanovic

Dr. Vladan Prodanovic, P.Eng., is very pleased to join the Departments of Chemical and Biological Engineering, and Mechanical Engineering as a senior instructor and Associate Director of the Clean Energy Master Program, and with the opportunity to work with young, energetic (pun intended) professionals and students who have a passion for sustainable practices in energy technologies. His professional interest and expertise is in the area of thermodynamics, heat transfer and multiphase flows.

Dr. Prodanovic has received his B.A.Sc. and M.A.Sc. in Chemical Engineering at the University of Belgrade, after which he worked as a researcher for several years at the Institute for Chemistry, Technology and Metallurgy, on topics in the area of multiphase flows and transport phenomena across phase boundaries. In 1995 he joined UBC to pursue a Ph.D. Mechanical Engineering, on the subject of Bubble Dynamics and Boiling Heat Transfer. Following his doctoral and postdoctoral studies at UBC, he transitioned to the Materials Engineering Department as research associate. His research projects, in collaboration with industrial partners such as ArcelorMittal Dofasco, Dillingen Hütte, Posco and Siemens, were related to jet impingement boiling and heat transfer modelling for improvement of cooling techniques during steel

production in hot strip and hot plate mills. This work was presented in over 30 journal and conference publications, and technical reports.

Although still involved in these research projects, over time his professional career has taken the direction of the academic teaching stream, based on a genuine interest in engineering education. In 2007 Dr. Prodanovic accepted an exciting offer to join the faculty of the newly formed School of Engineering on UBC's Okanagan campus, and participate in development of new the engineering programs. His particular interest was in developing the first year engineering curriculum, and implementation of engineering design through multidisciplinary project-based courses. A strong point he would always make was about the impact of engineering design on the environment and society. Having taught courses that are related to matter and energy conversion, Dr. Prodanovic regularly incorporated subjects topics related to alternative energy systems, clean energy practices, streamlining of matter and energy flows, design, redesign and improvement of equipment and conservation of energy in the building envelope. This interest in sustainable clean energy systems brought him to this Department where he currently teaches courses in the CEEN program.



Dr. Jane McCarthy

Jane McCarthy joined the Department at the end of 2013, as the Executive Assistant to the Head. The role is a complete career change for her. Originally from the UK, she gained her MSC in Manufacturing Management and PhD in Innovation Systems both at Cranfield University and then went on to join the faculty at Cranfield School of Management in the UK. After a few years though she

and her family moved to Vancouver and she opted for part time work in order to look after her young family. Over the past few years she has worked as a freelance academic editor and part time as a post-grad researcher at SFU. She is very much enjoying the challenge of taking on this different role at CHBE.



Photo credit Martin Dee

Above: CHBE Department Head Peter Englezos, Coop Director Jenny Reilly and IAC member Tony Hylton.

CHBE IAC

The Department's Industry Advisory Council (IAC) was convened in mid 2012. Since that time the Council members have been progressively becoming acquainted with the Department's research strengths and capabilities. As well as regular meetings as a whole group, the IAC is also divided into a number of subcommittees addressing specific areas of interest:

- Co-op and Undergraduate Student Professional Development
- Graduate Student Professional Development
- Development and Fundraising
- Research - University/Industry Collaboration

The IAC has become a dynamic and valued source of inspiration, ideas, feedback and advice for the Department.

UBC Engineering Co-op update

Last year's Exchanger featured a piece about the UBC Engineering Co-op. This exciting program offers students an opportunity to alternate course work with practical hands-on experience in the work place.

The students gain many times over with this program: work experience, improved specific engineering or lab skills, team working, learning about the wider business context of the work place, as well as developing industry networks and connections. Not least, the students learn how to market themselves successfully in today's work-

Our current IAC members are:

Claudio Arato, P.Eng. - Chief Technology Officer, Provectus Engineered Materials

Alfred Guenkel, P.Eng. - Partner & Principal Chemical Engineer, Noram Engineering & Constructors Ltd.

Paul Henderson, P.Eng. - Manager, Solid Waste, MetroVancouver

Eric Jervis - Principal Scientist, Stem Cell Technologies

Simon Malin - Regional Managing Director, Western North America, Hatch

George Peat - Executive Director, GERMMAX

Tim Watson, P.Eng. - Senior Vice President, Project Development, Teck Resources Limited

David Gandossi - Executive Vice President, CFO & Secretary, Mercer International Inc.

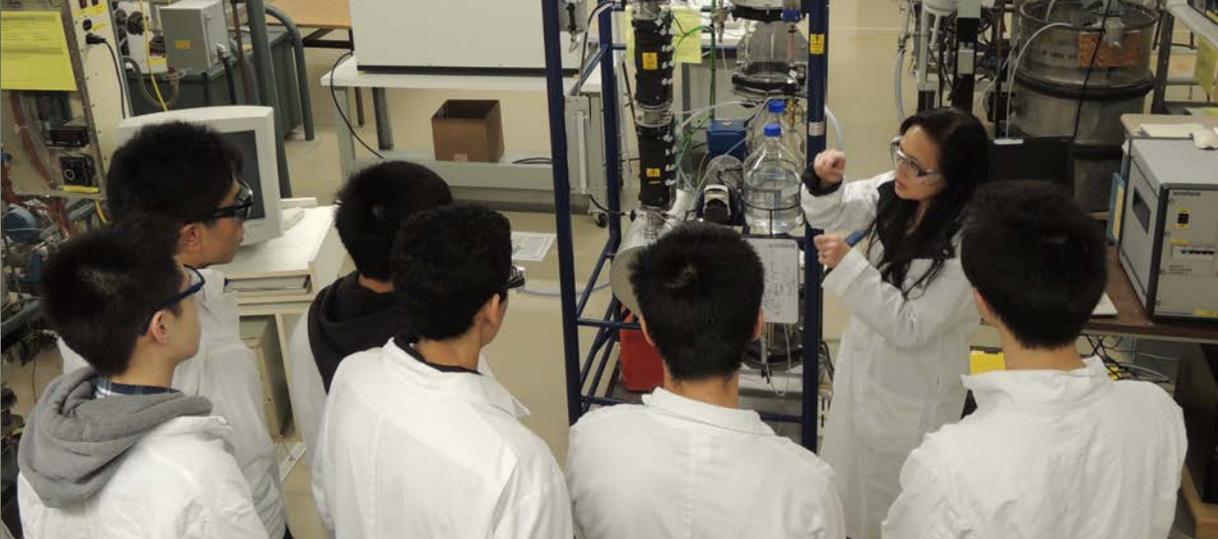
Paul Watson - Director, Canfor Pulp Research and Innovation

Peter Wynne, P.Eng. - Technical Specialist, Chevron Canada Limited

Carleigh Whitman - Director, Government Relations, Teck Resources Limited

place. Undoubtedly Engineering Co-op offers not only a helping hand but also a leg up for new graduates. Co-op is not a mandatory program, so students have a choice about whether to enrol or not. They are then responsible for applying for placements, and this process alone is great experience for them in presenting themselves. For their part, the Co-op office are active in seeking out work placement opportunities for the students, through strong links with industry.

All in all, in 2014, there were 180 students, both graduate and undergraduate, who signed up with the Co-op office. Of those, 166 were successful in securing work terms, a hit rate of 92%. The majority of placements were within BC and Alberta with companies such as ConocoPhillips Canada, TRIUMF, Teck Resources Limited, Ballard Power Systems Inc., BC Cancer Agency, Syncrude Canada Ltd., Suncor Energy and Shell Canada Ltd.



Above: Marlene Chow provides an undergraduate lab tour to ESEMP participants.

Tony Yang program

CHBE PhD student Tony Yang set out to inspire high school students to a career in engineering. To that end he started an outreach program, aimed at high school students, that brought the young students to UBC, to spend a weekend experiencing and learning about engineering.

His outreach program has now grown in strength and numbers and is now the Elite Scientists & Engineers Mentorship Program (ESEMP), administered by Elite Mentors Association, a BC-registered Non-Profit Organization founded in 2013.

The ESEMP mission is to provide an opportunity for motivated and hard-working high school students

(Grades 8-12) to explore advanced topics in Science and Engineering. Feedback and comments up to now have been very positive, a testament to the positive impact of the program.

Now ESEMP has grown to offer a 6-week introductory program that showcases some exciting science and engineering disciplines to successful program participants. Through this innovative program, participants will develop essential career skills, meet scientists and engineers, and explore cutting-edge research projects.

To date, over 300 high students have taken part in the program, coming from all over the Lower Mainland and, in Spring 2015, even from as far afield as Squamish.

Congratulations to Tony and his organisation on inspiring the next generation of engineering students.

FloBeau double success in 2014

There was double success in 2014 for FloBeau, a CHBE and Environmental Engineering (ENVE) undergraduate student design team. In May they won first prize for their 'real world' design at the BC Water and Waste Water Association. Student Design Competition, held in Whistler. This annual competition is now in its second year and was hosted by the BCWWA Young Professionals Committee and the UBC BCWWA Student Chapter. The FloBeau team was the lone undergraduate team at this event.

Success at the BCWWA event advanced the team to the Student Design Competition of the North American Water Environment Federation Annual Technical Exhibition and Conference (WEFTEC), held in September 2014 in New Orleans. At this event too, the FloBeau team was successful in winning first prize.

The winning design "Scenario Evaluation for Maintaining Baseflows and Water Quality in Star Creek" was inspired by a City of Coquitlam challenge to develop an innovative storm water management process that would simulate

the pre-development natural processes. The UBC project compared the feasibility and cost of three storm water management plans to aid the City of Coquitlam in determining how to proceed with a proposed development while protecting the salmon bearing stream of Star Creek.

The FloBeau team comprised Stephen Bertulli, Robert D'Amours, David Houghton, David Saabas, and Michael Thiessen.

Meet FloBeau

"As a team, we have a passion for design challenges and are eager to apply knowledge learned from classes and personal experience to practical design problems. We feel that this experience is valuable and that the skills learned over the course of these projects will translate well into a professional working environment."



MICHAEL THIESSEN

is currently working as an engineering summer student at McElhanney Consulting Services Ltd. in the water resources sector. He will be graduating from UNBC in December with a B.A.Sc. in Environmental Engineering and will pursue a career in storm water management or water/wastewater treatment. He enjoys rock climbing, mountaineering, cooking, and reading in his spare time.



ROBERT D'AMOURS

will graduate with a B.A.Sc. in Environmental Engineering from UNBC in December 2014. He currently works at Northwest Hydraulic Consultants, and looks forward to a career in water resource engineering. Robert plans to explore British Columbia while doing the work he loves, and might get some serious fishing done on the way.



STEPHEN BERTULLI

will be graduating from the environmental engineering program at UNBC/UBC in December. His primary interest is in water resource engineering and he is currently working, and enjoying his time, with Opus DaytonKnight. He enjoys staying active, team sports, reading, and good conversation over a single malt.



DAVID SAABAS

will graduate from the UNBC/UBC Environmental Engineering Program in December 2014. He intends to return to school to complete a MASC related to water resources or water treatment before working towards his P.Eng. He enjoys mountain biking, rock climbing, hiking, and generally having a good time in the outdoors.



DAVID HOUGHTON

will graduate as a Chemical Engineer from UBC in April 2015. He is currently a NSERC student research engineer working on fluidization and gasification of biomass at UBC. David's goal is to be involved in the recovery of resources from water and waste streams. He enjoys Vancouver's outdoor sports scene and traveling throughout the province in his spare time.



Above: Left to right – Dr. Jim Lim, Dr. Naoko Ellis, Ally Amin, Mary Kenny, Lee Rippon and Oliver Zihlmann

Thomas Bennett Award

On February 28, 2014, the University of British Columbia's Chemical and Biological Engineering Department hosted the award ceremony of the Thomas Bennett Student Enrichment Memorial Awards in Chemical and Biological Engineering.

This year's recipients, Ally Amin and Lee Rippon, were selected based on their participation in student enrichment activities, social and environmental concern, academic achievement and leadership qualities.

Chad Bennington Scholarship

The Chad Bennington Scholarship Award honours Dr. Chad Bennington, Professor in the Department of Chemical and Biological Engineering, who passed away suddenly on February 14, 2010. The scholarships are awarded to undergraduate students at UBC who demonstrate interest, leadership and academic accomplishment in pulp and paper technology.

The 2014 recipient of the Chad Bennington Scholarship was Michael Peters.

The awards were officially endowed in 2012 as a legacy of Thomas Edward James Bennett, an accomplished alumnus of the Chemical and Biological Engineering Department who graduated in 2007. During his time at UBC, Tom made a positive and lasting impression on students, staff, and faculty in the Faculty of Applied Science, many of whom were devastated by his untimely death in a tragic mountain climbing incident on April 1st, 2010, at the age of 26.

In attendance at this year's ceremony were the 2014 award recipients Ally Amin and Lee Rippon, Tom's mother Mary Kenny, CHBE professors Naoko Ellis, P.Eng., and Jim Lim, P.Eng., and Gladys Conroy and Oliver Zihlmann of UBC's Applied Science Development Office.

Right: Alireza Bagherzadeh receives his Graduate Student Leadership award from Dr. Peter Englezos.

Graduate Student Leadership Awards

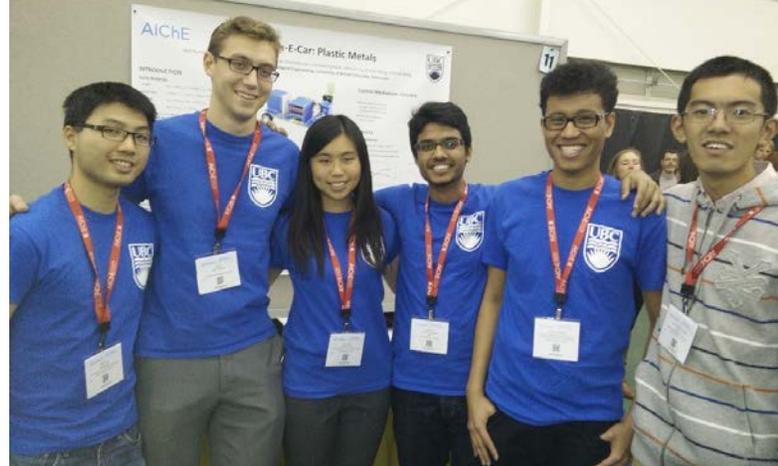
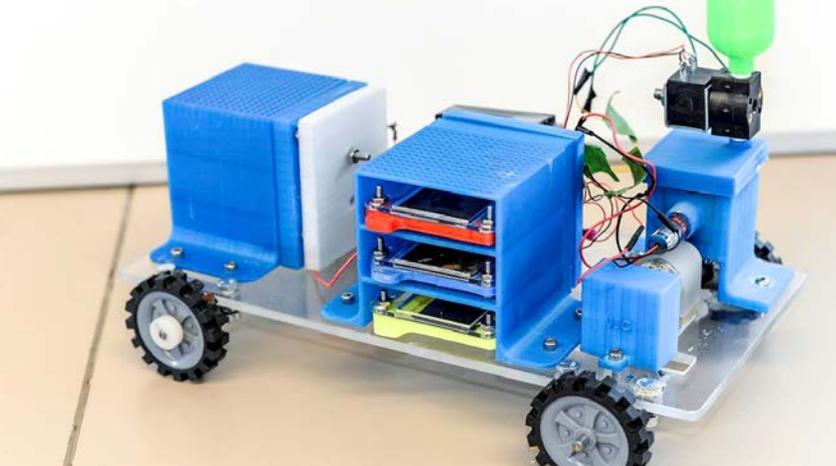
CHBE established the Graduate Student Leadership Award in 2013 'to identify those who have played a significant leadership role in his or her activities and in so doing has had a demonstrable impact on improving the quality of student experience at CHBE'. The 2014 recipients were Alireza Bagherzadeh and Hafiz Rahman. Their excellent work as student leaders was recognized by the awards.

As the chair of the organizing committee of Research Day 2014, Alireza Bagherzadeh provided outstanding leadership and worked countless hours in organizing this event. Alireza obtained a Masters degree from the Department, and is currently working with Professor Peter Englezos. He has also served as the Vice President of CHBE Graduate Students Club for a couple of years.

In 2011, Hafiz Rahman launched and then ran the unique 'Professional Development Speaker Series' on behalf of the CHBE Graduate Students Club. The Speaker Series invited academics and industry leaders

to present to club members and share their experiences and impressions. Through these seminars, he has made exceptional contribution to the professional development of graduate students in CHBE and other engineering departments at UBC. Under his extraordinary leadership as the President, the CHBE Graduate Students Club has successfully advocated on behalf of graduate students for enhancing the quality of graduate student experiences in the Department. Hafiz has a Masters degree from the University of Alberta and is currently working under the supervision of Professors John Grace, P.Eng., Jim Lim, P.Eng., and Xiaotao Bi, P.Eng.





UBC Chem-E-Car 2014

The Chem-E-Car challenge is aimed at providing chemical engineering students with the opportunity to participate in a team-oriented hands-on design project to construct a small model car. The car must be powered with a chemical energy source and be capable of carrying a specified load over a given distance before coming to a stop. The idea behind this is for the teams to demonstrate their ability to safely control a chemical reaction by changing the chemical reactant(s).

CHBE students have enthusiastically and successfully participated in this competition for several years running. In April 2014, the UBC Chem-E-Car team placed 1st in their Pacific Northwest Regional competition advancing them to the final round of competition. The team travelled to Atlanta, Georgia to compete in the AIChE National Chem-E-Car competition on November 15-16. Competing with a car powered by student designed zinc-air batteries, the team finally placed 8th out of 36 qualifying teams from around the world.

The competition involves building an autonomous shoe-box sized car and powering it using a student-designed chemical reaction. The goal is to stop the car at a given distance while carrying a payload using chemical timing only (mechanical and/or electronic timing is not allowed). The distance and payload is announced 1 hour prior to the performance competition and students then use that

hour to calculate and prepare their chemicals before racing their cars. The team who stops closest to the finish line is declared the winner. This year's distance was 25.6 m while carrying a payload of 244 grams. Despite almost running out of chemicals, the team still managed to stop 98 cm from the finish line.

The CHBE car was powered by zinc-air batteries using air MnOx cathodes by Gaskatel housed in student designed casings. The team improved on last year's iodine clock reactor to allow for continuous stirring to improve chemical timing. Printed circuit boards were manufactured to ensure that the electronic connections were more robust.

The Chem-E-Car team's collaboration with UBC Rapid, a club that designs and builds 3D printers, has allowed the Chem-E-Car team to utilize 3D printing for the majority of the components on the car including the battery casings. For parts that could not be 3D printed or laser cut, the team made use of CHBE Department's helpful machine shop.

Guided by veteran members, the newly formed 2015 team is seeking to optimize the battery dimensions and chemical timing for the regional competition which will be held at UBC in the spring of 2015.

The team acknowledges graduate student, Andrew Wang, for ensuring safety in laboratory sessions and guidance as needed. They also thank Marlene Chow, P.Eng., Dr. Elod Gyenge, P.Eng., Dr. Madjid Mohseni, P.Eng., and Dr. Bhushan Gopaluni, P.Eng., for actively supporting the team.

Top Right: Travelling team members from left to right: Norvin Ng, Joel Kumlin, Colleen Chau, Abhi Kamble, Ruben Govindarajan, Johnson Liu.

Top Left: UBC Chem-E-Car's competition vehicle, Plastic Metals, ready to compete.

Hafiz Rahman wins Killam Graduate Teaching Award

Congratulations to Hafiz Rahman, CHBE PhD candidate, for winning the UBC Killam Graduate Teaching Award, for his outstanding contribution to teaching. His energy, enthusiasm and diligence in fulfilling his teaching responsibilities have made a positive impact on the quality of the learning environment at UBC.

Hafiz has a Masters degree from the University of Alberta and is currently working under the supervision of Drs. Bi, Grace and Lim. Hafiz is also the President of the CHBE Graduate Student Club.

The Killam GT Awards have been presented annually since 1996 to sixteen of the best UBC Teaching Assistants, in recognition of the valuable role that teaching assistants play in undergraduate programs. With over 2,000 Teaching Assistants working at UBC, this represents a significant achievement.



CRC for Dr. Curtis Berlinguette

Dr. Curtis P. Berlinguette was among 13 new UBC Canada Research Chairs recently announced. He has already held a Tier II Canada Research Chair (CRC) in Energy Conversion at the University of Calgary, prior to his move to UBC as Associate Professor of Chemistry and Chemical & Biological Engineering.

His new CRC is in Solar Energy Conversion and he leads a research team working on designing new materials to convert sunlight into electricity and finding economically viable ways to store that energy in clean hydrogen fuels. Dr. Berlinguette has built up an internationally recognized research program in the area of solar energy conversion. His contributions have previously been recognized with a prestigious Alfred P. Sloan Research Fellowship.



Dr. Xiaotao Bi Fellow of Canadian Academy of Engineering

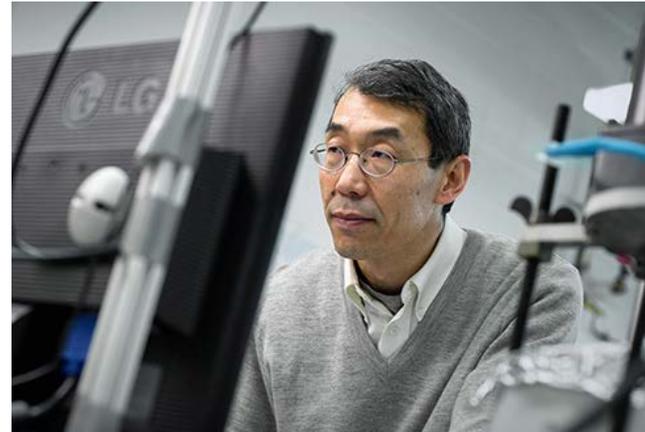
Dr. Xiaotao Bi, P.Eng., was one of 49 new Fellows inducted into the Canadian Academy of Engineering at a ceremony that took place in Saint John's on June 26, 2014 in conjunction with the Academy's 2014 Annual General Meeting and Symposium.

Professor Bi has been with the Department since 1997. He has established an internationally recognized research program with excellent industrial support from Canadian and International organizations. His scientific and technical research contributions have been outstanding with impact in the fields of fluidization, fluid-particle flow systems and bio-energy. Dr Bi has also led the development and introduction of Departmental courses in the area of green process engineering.

Peter Wall Institute Scholar – Dr. Jimmy Feng

CHBE's Dr. Jimmy Feng, P.Eng., was appointed a Peter Wall Institute for Advanced Studies UBC Scholar for 2014 – 2015. Dr. Feng plans to use his year in residence to carry out research in modeling cell mechanics, tissue morphogenesis and ferro-fluid self-assembly during his year in residence.

The Institute's Wall Scholars Research Award grants appointed UBC Faculty members a one year in residence at the Peter Wall Institute in a collaborative, interdisciplinary environment. Dr. Feng holds a Canada Research Chair in Complex Fluids and Interfaces and a joint appointment with UBC's Department of Mathematics. His inter-disciplinary work seeks to exploit mixtures of complex fluids for novel engineering and biomedical applications, such as improved processes for controlled drug release and investigations into the dynamics of pathological cells—damaged red blood cells found in malaria and cancer.



Dr. Savvas Hatzikiriakos Receives Canadian Rheology Award

Chemical and Biological Engineering Professor Savvas Hatzikiriakos, P.Eng., has won the 2014 Canadian Society of Rheology Stanley G. Mason Award. The triennial award recognizes an individual who has made outstanding contributions to the field of rheology – the study of the flow and deformation of matter under applied force. Dr. Hatzikiriakos is a distinguished rheologist who has lent his innovative expertise to companies such as DuPont, ExxonMobil and Chevron. His research areas include polymer rheology, processing and surface science.



A Stellar Year for Dr. David Wilkinson

Some years pass by quietly and unremarkably, but some more rare ones seem to bring all the rewards of labour at once. CHBE's Professor David Wilkinson, P.Eng., had just such year in 2014. In April, he received the prestigious Grove Medal Award, a distinction awarded to those who have made valuable contributions towards the development and success of fuel cell technology.

In November he was made a Fellow of the Royal Society of Canada, the highest distinction a scholar can achieve in the arts, humanities and the natural and social sciences.

Also in 2014, he was made the recipient of the R.S. Jane Memorial Award, presented to a person who has made an exceptional achievement to the field of chemical engineering or industrial chemistry.

Finally, in 2014 he was recognized by Thomson Reuters as a "Thomson Reuters Highly Cited Researcher" in recognition of ranking in the top 1% of researchers for most cited documents in their specific field. This is based on assessing papers between 2002 and 2012 in 21 broad fields of study. A further recognition from Thomson Reuters was to be listed in the "The World's Most Influential Scientific Minds in 2014".

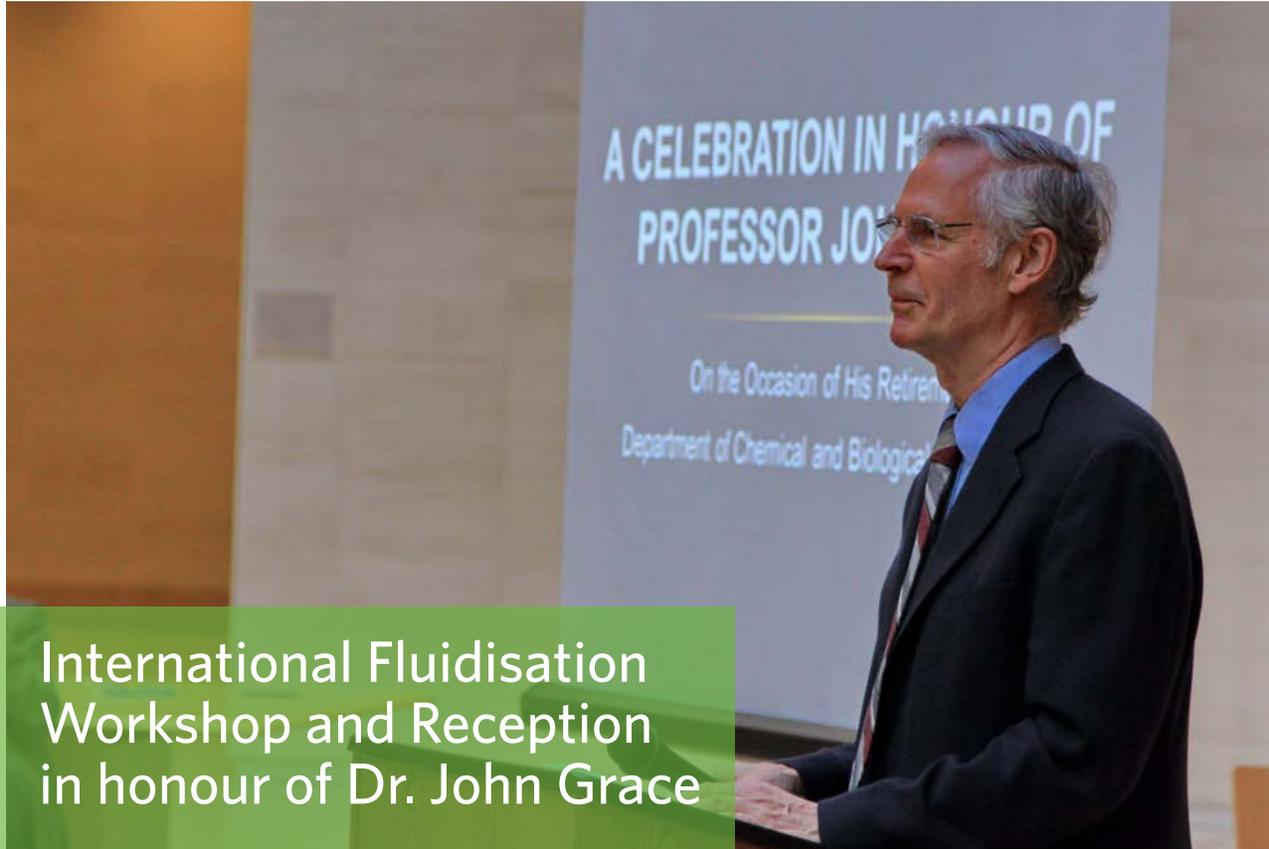
Dr. David P. Wilkinson received his BAsC Degree in Chemical Engineering from the University of British Columbia (UBC) in 1978 and his PhD degree in Chemistry from the University of Ottawa in 1987.

Dr. Wilkinson began his career in industry. At Moli Energy, he was part of the team that developed the world's first commercial rechargeable lithium AA battery. Subsequently he was the Director, and then Vice President of Research at Ballard Power Systems Inc., involved with the research, development and application of fuel cell technology.

At UBC, Dr. Wilkinson has held a Tier 1 Canada Research Chair in Clean Energy and Fuel Cells since 2004 and has been the Director of the UBC Clean Energy Research Center (CERC) for the last four years. He has also maintained a joint appointment with the National Research Council Institute for Fuel Cell Innovation for several years where he was a Principal Research Officer and a senior advisor.

Dr. Wilkinson has received a number of awards for his work including the R.A. McLachlan Award, the highest award for professional engineering in British Columbia; the Electrochemical Society Battery Division Technology Award; and a Lifetime Achievement Award from the Canadian Hydrogen and Fuel Cells Association. Dr. Wilkinson's main research interests are in electrochemical and photochemical power devices and processes to create clean and sustainable energy. He has over 75 patents and 145 publications covering innovative research in these fields.

We truly congratulate Dr. Wilkinson on a stellar year and on his well-deserved success and recognition and we are proud to number him among our faculty.



International Fluidisation Workshop and Reception in honour of Dr. John Grace

Above: Dr. John Grace addressing the audience at his retirement reception

Bottom Left: Dr. Naoko Ellis opening for Dr. John Grace's retirement

Bottom Right: Reception for Dr. John Grace

In June 2014, the Department held a gala Reception in honour of Dr. John Grace, P.Eng. The occasion celebrated Dr. Grace's many contributions and achievements. It also formally marked the occasion of his retirement.

The Reception took place at the end of the International Workshop on Fluid Particle Systems, held in honour of Dr. Grace for his lifetime endeavours in research and education. This international workshop on Fluid-Particle Systems was held at the Department's Fluidization Research Centre, June 26 and 27, 2014. The workshop provided an opportunity for the presentation and discussion of recent advances in fluidization, fluid-particle systems, multiphase heat/mass transfer and

reactor design. The program included keynote speakers and oral and poster presentations. Conference chairs were Professor Xiaotao Bi, P.Eng., Professor Naoko Ellis, and Adjunct Professor Roland Clift.

Following the workshop, the Reception took place at the East Atrium of the UBC Life Sciences Centre and was well attended by over 150 guests, Dr. Grace's colleagues and students, past and present, as well as friends and family. Numerous speeches referred back to Dr. Grace's long career, with fond memories revisited by past colleagues and students. Current colleagues, including Dean Marc Parlange, also paid tribute to Dr. Grace. The presentation of a gift from the Department, by Dr. Englezos rounded off the event.





CHBE Graduate Student Club Update

Each year the CHBE Graduate Student Club (GSC) organize and host a number of academic and social activities and events. In 2014, the club focused its efforts particularly on creating a more engaging social atmosphere for CHBE graduate students.

With this goal in mind, the club executive team organized a number of social events for CHBE graduate students, staff and faculty members, including a weekly Coffee Break, a Halloween Pumpkin Carving Contest and the CHBE Annual Christmas Party.

Halloween Pumpkin Carving Contest

The CHBE graduate students have very diverse cultural backgrounds. The GSC brings together all these diverse cultures to share this fun North American tradition. With the Department's support, the GSC hosted a pumpkin carving contest among CHBE graduate students, faculty, and staff members on the evening October 31st, 2014.

Coffee Break

With the Department's support, the GSC arranges this social event at the faculty lounge every Friday at 3 PM after the weekly seminar. The goal is to bring together CHBE faculty, staff, visiting scholars, post-doctoral fellows, and graduate students. Over the past several years, this event has attracted 10 to 20 graduate students weekly. Students share cookies and other snacks, sometimes homemade, along with coffee or tea. The Coffee Breaks also serve as a focus for special events for CHBE graduates, such as a farewell to many of the European students and a special Salad Day event.

Annual Christmas Party

Every year, the GSC assists the Department in hosting a festive gathering of CHBE faculty, staff, visiting scholars, post-doctoral fellows and graduate students. This year, due to tight examination schedules, the party was held on December 3rd during lunch hours in a CHBE seminar room. The executive team dedicated much effort to decorating the room and arranging food services to create a festive theme and to satisfying special requests from each cultural and ethnic group.

Top Left: Grad Club Pumpkin Carving competitors with their creative award winning entries.

Top Right: Amin Nouri enjoying the Grad Club Christmas luncheon.

Interdepartmental Party 2014

On January 31, 2014, the CHBE Graduate Student Club was invited, for the first time, by Mechanical Engineering Grad Student Association (MEGA) to contribute to the Interdepartmental Party. This is a social mixer event jointly organized by five graduate student associations: Mechanical Engineering, Chemical & Biological

Engineering, Bio-Medical Engineering, Neuroscience and Architecture & Landscape Architecture in conjunction with the interdisciplinary Graduate Student Network (iGSN). The party was held in the Thea Lounge in the Graduate Student Society (GSS) Building. The purpose of this social event is to encourage graduate students to go out from their home Department and share ideas with students from other Departments. The attendees socialized informally and enjoyed the buffet food available. The event was overwhelmingly successful with 150 total attendees.

Right: Research Day delegates in the Chemical and Biological Engineering Building Atrium.

CHBE Graduate Research Day

CHBE Research Day 2014 was successfully held on October 1, 2014 at the Chemical and Biological Engineering Department (CHBE). Research Day is a graduate student initiative, established in 2013, and run by graduate students with support from CHBE faculty members. The objectives of this whole-day event are to showcase the research work conducted at CHBE as well as the other engineering Departments across the faculty of applied science at UBC; to promote industry-academia partnership at the graduate level; and to provide many opportunities for engineering graduate students to network with the broader local community and industry representatives

Over 135 delegates from industry, local community and across UBC engineering Departments attended the Research Day this year. Interesting and insightful keynote talks by Dr. Michael Hoffmann from California Institute of Technology and Dr. Roger Gaudreault from Cascades Canada were among the highlights of the day.

A distinguished industry panel included Dr. Alfred Guenkel (NORAM), Dr. Eric Jervis (Stemcell Technologies), Dr. Wayne Brown (Coanda Research & Development) and



Dr. David Bruce (ZyncNyx). The panel answered engineering graduate students' questions about job strategies, skills requirements and career development. Research Day presentations of research were both well subscribed and well attended. Towards the end of the event, there were awards for the top two oral presenters and the top three poster presenters. The awards were presented by Dr. Marc Parlange, Dean of the Faculty Applied Science, UBC, who graciously supported the event.

The event also played host to the 2014 CHBE Graduate Student Leadership Award, which this year went jointly to Hafiz Rahman and to Alireza Bagherzadeh.

Above: Undergraduate team left to right: Kareem Awad, Philip Chow, Nick Armitage, Marcus Yu, Connor Reid, Philip Jones, Farbod Rahiminejad, Matt Asaminew, Roberta Neuman, Stacie Hurst, Onjaree Chongpaisansakul, David Houghton, Kimia Yageneh, Przemyslaw Piwek, Magdeline Lenta, Matthew, Liam Arnold, Shedia Arfania, Tyler Wood, Pranav Bajaj, Tony Wu.

Undergrad Club Updates

Over the course of each academic year, the Undergraduate Student Club organize and run numerous events aimed at bringing the undergraduates together to create a sense of community and common purpose, disseminate information and celebrate successes. From Imagine Day on the first day of term, to organizing the Grad Boat Cruise for the graduating students of each year, the Undergraduate Student Club keeps everyone connected and involved.

Below: The CHBE Chariot Race Team left to right: JP Faucher, James Stewart, Teboho Sefuthi, Sheida Arfina, Tony Wu.

Iron Ring Ceremony

The Iron Ring Ceremony took place on Wednesday March 18 at the Queen Elizabeth theatre. The tradition of "Calling an Engineer" which goes back to 1925, and was initiated by Mr. Kipling, aims to connect Canadian Engineers in a special way.

Imagine Day

The first day of classes is known as **Imagine Day**, when the UBC campus welcome more than 8,000 new students. CHBE had a very successful Imagine Day 2014. The CHBE Undergraduate Club, with the help of the department, ran lab tours and a delicious BBQ, all to the sounds of live music.



Open Houses and First Year Club Crawl

Numerous events are held to help introduce and orient first year students to CHBE and to showcase some of the student work done in the Department. One of these events was Open House in the beginning of March as well as the Club Crawl at the end of March.

Industry Night

On March 26, 2014, the CHBE Undergraduate Club, with the help of the Chemical & Biological Engineering Department, held a successful Industry Panel Night, inviting local engineers to showcase their work and answer questions regarding their careers and the job market. Light refreshments were provided in the atrium. Companies present included Chevron, Solaris, BC Hydro, and STEM Cell Technologies.

On November 3, 2014, a "Speed Networking" industry night was held at Coppertank, with the help of the Alumni Relations Office. It was a very popular event and

many mentors and alumni from many local companies were present. Some of the companies present included Solaris, Chevron, Imperial Oil, Spartan Controls, Mantra Energy, David Alpin Group, AMEX, AECOM, NRC, Proectus Engineered Materials, Chemetics Inc., and Tri-Y Environmental Research Institute.

Western Engineering Competition

Congratulations to CHBE students Bao Man Liu ('15), Tyler Pfanner ('15) and Lisa Lee ('16) for achieving second place in the Consulting Category at the Western Engineering Competition (WEC) held in Vancouver, January 22-26. The team presented their approach to The Construction of an Ethylene Glycol Plant in Richmond to a panel of judges after 8 hours of problem solving. They will represent Western Canada at the Canadian Engineering Competition this year held in St John's, March 4-6, 2015.

Update submitted by Kimia Yeganeh,
U/G Club President



E-WEEK

E-WEEK happened in the first week of February. Thanks to all the CHBE's who participated in E-WEEK this year!

Engineer's Ball

What a better way to say goodbye to E-WEEK but the 96th Annual Engineer's Ball! Many CHBEs attended the event and had a great time.

Graduation Day

The Graduation Day Reception 2014 was a happy event attended by our new graduates, their families, our faculty and many of the staff who turned out to share in the excitement.

The Reception was held in our building atrium and in auditorium Rm 101. It was an opportunity to recognize the achievements of exceptional students as well as some exceptional teachers! Speeches and awards were made in Rm 101 and there were delicious refreshments in the atrium afterwards.

The Shell Award and the ICGH Hydrates awards are given out as prizes to the best capstone design project teams on Graduation Day. In 2014, the two winning Shell teams were:

BEST BIOPROCESS DESIGN - *Improving Greek Yogurt's Environmental Impact*: Alyssa Brownlee, Susan Cherboror, Benedict Duenas, Andrew Dusevic, Young Kim, Olivia Mais, Jae Yun Park

THE EXCHANGER SPRING 2015

BEST CHEMICAL PROCESS DESIGN - *A Strategic Approach to Producing DME by Upgrading the Abundance of Natural Gas in Qatar*: Jeffrey Lam, Joseph Lam, Ariel Magpantay, Norman Siu, Danny Zi Tao, James Wong, Chenlong Xie

THE WINNING ICGH HYDRATES TEAM - *Recovery of the Flare Gas for Liquid Hydrocarbons*: Sara Behairy, Derek Fong, Roderic Ho, Courtney Radway, Thitikorn Stitsupamas, Suwachira Vijitpornkul, Peng Yao Wang

Teaching awards are made in recognition of excellence in teaching, as voted by the student body each year. The 2014 teaching awards went to Dr. Xiaotao Bi and Dr. Louise Creagh.

Congratulations to all recipients.



Bottom Left: Best Chemical Process Design Team

Bottom Right: Best Bioprocess Design Team

The Oil & Gas Initiative

 /theoilandgasinitiative

CHBE Oil and Gas Initiative

The CHBE Oil and Gas Initiative was formed to provide connections between UBC engineering students and the oil and gas industries of Canada. The Initiative creates awareness of the industry, promotes related events taking place on campus and hosts events itself all with the aim of enabling better links with the industry for UBC students.

The oil and gas industry has a huge impact on the Canadian economy and for young engineers is moreover a source of jobs, careers, wealth, knowledge and expertise.

Over 2014, the CHBE Oil and Gas Initiative participated and led a number of exciting events:

- Promoted industry events of Chevron, Shell and Devon Energy on Campus.
- Hosted Talk on The Evolution of Drilling Technology by partnering up with Remedy Energy Services.

- Created videos on UBC CHBE-Coop students to share their work experience.
- Hosted talk about Development of Natural Gas Industry by Professor Michael Schoen.
- Interviewed Coop Students to share their work experience.
- Integrated as UBC's first ever student chapter of the Society of Petroleum Engineers.
- Secured Sponsorship with Shell Canada for the year 2014-2015.
- Collaborated with students from UBC School of Journalism in writing papers about the falling oil prices and its effects on Canadian import and export.
- Researched and have written reports on the sustainable measures taken by the oil and gas companies in Canada like Suncor Energy and Cenovus Energy.

There are equally ambitious plans for 2015, so watch this space.

Right: YES delegates examine posters in the Chemical and Biological Engineering Atrium.

CHBE hosts second annual YES, July 2014

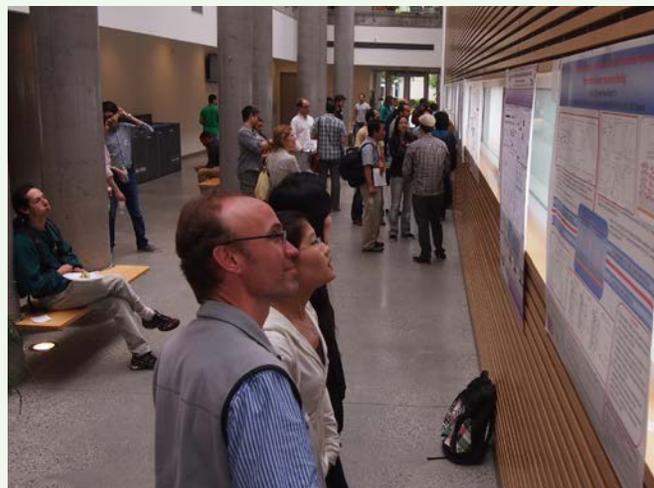
CHBE were the proud hosts, in July 2014, of the second annual BC Young Electrochemists Symposium (YES), held by the Electrochemical Society of BC (ECSBC) Student Chapter. The symposium was jointly sponsored by ECS and CHBE.

The ECSBC Student Chapter strives to foster interaction among students, professors, researchers, and industry experts interested in the field of electrochemistry in British Columbia.

The one-day symposium included presentations and a student poster presentation session, with prizes for the best research posters. The presentations were by Dr. Curtis Berlinguette (UBC), Dr. Hogan Yu (SFU), Dr. Amin Aziznia (Mantra Energy Alternatives Ltd.), Dr. Thomas Kadyk (SFU) and Dr. Alix Melchy (SFU).

Two cash prizes and one honorary gift were awarded to the best posters by Heather Baroody (1st), Huihui Tian (2nd) and Sean McBeath (3rd) in the poster competition.

The event attracted more than fifty-five attendees from UBC, Simon Fraser and western Washington universities and from industry.



West 2014

The inaugural Water & Environment Student Talks (WEST) took place this June at UBC. The conference brought together graduate students, young professionals and academics from across the Pacific Northwest.

WEST hosted over 35 student talks on water treatment, stormwater management, water pollution control and water policy. The conference team also brought in David Anderson, a former federal Environment Minister, Drs. Kathryn Harrison and John Grace from UBC, Jack Cooley from the Squamish Streamkeepers Society, and Jana McLean, an environmental lawyer, to bring valuable insight and seasoned perspectives to the event.

The conference was a concerted effort by a team of graduate students in the civil and chemical engineering Departments to bring the water community together. The feedback received from delegates has been so positive that the organizers are already preparing for next year's event. The team hopes that the conference will become an annual event and will grow to include other researchers and young professionals in the region, building and strengthening an effective interdisciplinary water community.



The CHBE Sustainability Club

The CHBE Sustainability Club was launched in 2006 with the mission of serving as a model of sustainability and to foster a true culture of sustainability in the Department and on campus. In spring 2014, the Club spearheaded the founding of the first non-US chapter of Engineers for a Sustainable World (ESW).

ESW is a non-profit organization created to promote sustainability awareness and projects among engineering students (www.eswusa.org). There are over 30 university chapters in the US, but the UBC chapter is the only one outside of the US so far.

The newly rebranded UBC Engineers for a Sustainable World, has just over 15 active members. The Club holds weekly meetings in the Department, organises and runs events, seminars and a speaker series and showcases sustainability research. Recent speaker series topics include the Alberta oil sands and clean water.

The Club has been very active in advocating for waste reduction and better recycling in the Department. The

Club website lists a number of different categories of waste and where they can be collected in the Department; this includes everything from compostable waste, to printer cartridges, to laboratory plastic waste.

A key project has been the Biodiesel Project, which aims to produce biodiesel on a pilot scale for use in the campus community. Biodiesel is a renewable, clean-burning replacement for diesel fuel, made from a diverse mix of oils and fats, including recycled cooking oil, soybean oil, and animal fats. The Biodiesel Project has been able to produce biodiesel economically from waste oils produced by the UBC campus community. There are currently plans for a plant upgrade, organized by Enactus, a group of Sauder students involved in this project.

As a side project the club uses the glycerine by-product of this production process, to produce liquid soap for use in the chemical engineering labs. Coffee-scented soap has been the most recent experiment.

The Biodiesel project has attracted funding from AMS Sustainability Fund, UBC Applied Science PAF Fund, Cooperators IMPACT Fund and UBC Work Study/Learn.

Below: CHBE Sustainability Club left to right: John Deppe, Greg Afonso, Tyler Wood, Golnar Mozafari, James Butler, Negin Tousi, Angie Moody, Jan Laescke, Kimia Yaganeh, Mehdi Badheri, Neona Chan, Tim Cai, James Kuo, Naoko Ellis, Torsten Jaccard.





Above: Third Year students at Zellstoff Celgar Pulp Mill walking on the pedway under the lime kiln.

Below: Third Year students observing the overhead crane unload a load of logs at the Zellstoff Celgar Pulp Mill Woodroom.

Third Year Field Trip

The Third Year Chemical and Biological Engineering Field Trip took place September 22 to 27, 2014. The trip was effective in showcasing various industries and operations involving process engineering.

The first visit, on September 23, was to the Zellstoff Celgar kraft pulp and paper mill, in Castlegar. Celgar manufactures high grade northern bleached softwood kraft and the students got to see how wood chips are converted into pulp. The full day tour of the pulp and paper mill also included an overview of the effluent treatment and the reuse of by-products, highlighting the important environment and green energy components that engineers must also now think about in order to achieve success. Prior to the on-site tour, students were treated to presentations by the Zellstoff Celgar staff. The operational manager of Celgar, a CHBE alumnus, gave us a great presentation about his journey from CHBE to Celgar, which was very exciting to hear. The passion of both employees and staff throughout the day showed and they went all-out to make the visiting CHBE students and instructors feel welcome.

On the evening of September 24, the students attended a dinner hosted by Shell at the Calgary International Hotel. The dinner served as a networking session for students and Shell staff. Each table had at least one Shell employee who talked about their experiences, opportunities, and operations at the organization. The keynote speaker gave an important speech about her path to joining and moving up the ranks of Shell as well as touching on the international opportunities that exist within Shell. An important component of the keynote speech was the

“things I wish someone had told me when I was in your position” component, where important challenges the speaker faced in networking and succeeding at work were shared with the students. The speech was inspiring and motivating. Something that also was beneficial was the large number of CHBE alumni that were at the dinner.

The following day the group visited Shell’s Caroline Gas plant as well as its Sulphur Refining plant. The tours hosted by Shell were definitely very informative. At Caroline, being able to see heat exchangers, separators, and other process instrumentation first-hand at such a large scale was a highlight. For many, it was the first time they saw how all these unit operations connect in such a grand scheme. Having the required protective equipment also allowed the group to get a closer look on the process mechanisms. The tour guides were enthusiastic and eager to ask questions. The Shantz plant was a smaller operation however the discussion was very thorough and detailed. Students were able to really gain understanding of the full operation undertaken at Shantz and got to see some very interesting sites, such as where all the sulphur pellets are stored. The tour guides were very helpful in answering questions.

On September 26, 2014 the students visited Agrium in Carseland and the Bonnybrooke Wastewater Treatment plant in Calgary. The wastewater treatment plant was highly beneficial for students taking CHBE 373, as they got to see the primary and secondary treatment as well as the use of clarifiers, digesters and UV treatment. Agrium showed us how they produce ammonium and urea for fertilizers through a detailed presentation led by a CHBE alumnus as well as an on-site tour. The tour was beneficial as it included multiple unit operations, reactors and heat exchangers.



This trip gave the students a chance to see large-scale industries while getting the opportunity to network with professionals and ask questions during the process. Hopefully the trip introduced possible options for future employment in these industries to students. The trip also brought our class closer together as a community and has definitely ignited a sense of drive and passion in the Chemical and Biological Engineering students.

I want to thank the following people for all their help with the planning and resourcefulness on the trip: Marlene Chow, Susan Baldwin, Heather Trajano, Ehsan Behzadfar and Perry Ian Liong Dhat Wong Shui Wan. I also would like to thank Shell, Zelstoff Celgar, Agrium Carseland and the Calgary Bonnybrook Water Treatment Plant, and their employees for giving us the chance to have this field trip. It was also an opportunity to network with professionals and to gain a better understanding of opportunities available to us in industry.

This article was prepared by Farbod Rahimi-Nejad, one of the 3rd Year organizing committee.



Norman Epstein Portrait

On the initiative of the CHBE Graduate Club, with support from the CHBE Department, a portrait was commissioned of Dr. Norman Epstein, in honour of his 90th birthday. The portrait was painted by Dr. David Bruce, recent graduate of the CHBE Graduate program. The portrait was unveiled at a small reception on April 4, 2014, in the Norman Epstein Reading Room, where the portrait will hang.

The event had a great turnout and Dr. Epstein was very pleased with his portrait.



Below: Left to right - Dave Fisher, Stanley Tam, Hans Larsen, John Cassin, Ian Isbister, Randy Wunderlich, John Wearing, Dave Code, Barry Jessup, Dr. Peter Englezos - Head, Chemical & Biological Engineering.
(Other attendees missing from this photo: Kuldip Bindra & Al Smith)

Chem Eng Class of '74 Reunion

On the weekend of September 19-20, 2014, the Engineering Class of 1974 (all Departments) celebrated its 40th anniversary. The organizing committee did a tremendous job with a Beer Night Reception at the Arbutus Club on Friday evening and then an excellent Buffet Dinner at the University Golf Club on Saturday

night. Both events were well attended and it was fulfilling to be back in touch with such a good group of grads.

Eleven of the original 25 Chem Eng grads from that year not only attended the Friday/Saturday activities, but also were fortunate to have a personalized tour of the new Chemical & Biological Engineering Building. We particularly appreciated the Department Head, Dr. Peter Englezos, P.Eng., taking the time to provide a brief history and context to the changes in the Department over the years and it is gratifying to know that the Department will be celebrating its 100 years anniversary next year. What an excellent facility for undergrads, grad students and faculty (although, they had hidden the ping pong table so that we would not be distracted). Congratulations to the tireless efforts by the faculty to stimulate and prepare the current generation of chemical and biological engineering students.

We were also most fortunate to have a luncheon with 3 of our prior professors and distinguished Professor Emeriti: Dr. Norman Epstein, P.Eng., Dr. Richard Branion, P.Eng., and Dr. Paul Watkinson, P.Eng. Their continued dedication and contribution to the Chemical and Biological Engineering Department and all the students over the years is certainly outstanding.

Submitted by Barry Jessup, BASc '74 CHML



Photo credit: Stanley & Jane Tam

Below Left to Right: Chem Eng 1964 attendees: Tom Skupa, John Morgan, Lawford Dupres, Don Macdonald, Gordon Thomson, Walter Hogg, Ron Pratt, George Percy, Robin Booth, Peter Shepard, Ron Anderson, Jim McClennan, Bernie Poplack, Jack Selby, and Dean Marc Parlange. Also attending Claude Sam and Ken Dobell.

Chemical Engineering 1964 50th Reunion at UBC

The Chemical Engineering class of 1964 celebrated their 50th anniversary at Alumni Weekend May 23 and 24. But this wasn't the first time this remarkable class has celebrated an anniversary. For 50 years the class has come together with a yearly newsletter. And for their 25th and 40th years they celebrated at private gatherings in Vancouver.

Sixteen of the surviving 22 of 25 graduates attended, many with their wives. On May 23 they gathered for an informal dinner party at the Boathouse Bar on Kitsilano Beach. Old friendships and camaraderie resulted in a raucous party even though all are over 70 years old.

On May 24 the class joined other engineering grads for a pancake breakfast in the atrium of new Chemical and Biological Engineering building. Dean Marc Parlange gave a spirited lecture on the current state of Applied Science and his objectives for future excellence. CHBE Head Doctor Peter Englezos, P.Eng., gave the class a private briefing on the department and conducted a tour of the facility.

The highlight of May 24 was a luncheon at Royal Vancouver Yacht Club attended by Dr. Englezos and Professor Emeritus Dr. Norman Epstein, P.Eng. Epstein was one of the principle professors who taught the class. He is revered by all class members, so it was a very special treat to interact with him on this occasion. All in, a very memorable and fulfilling time for all!

Submitted by Gordon Thomson, BASc '64 CHML



Photo Credit: Gordon Thomson

Speaker Series 2014

Graduate Club Professional Seminar Series

The Graduate Club Professional Seminar Series was launched in 2011. The series invited academics and industry leaders to share their experiences, career progress and lessons. The 2014 speakers were:

- Mr. Claudio Arato, P.Eng. | Director, Engineering, Sonoro Energy | January 13, 2014 | Applications in Engineering – Opportunity & Risk in a Changing World
- Dr. Patrick Littlejohn | Senior Technology Development Specialist, BioteQ Environmental Technologies | February 17, 2014 | Public Speaking for Engineering Grad Students
- Dr. Eric Jervis | Principal Scientist, Stemcell Technologies | March 31, 2014 | What do I wish someone had told me 20 years ago – and what has changed since
- Dr. Mattheos Koffas | Associate Professor of Biology, Rensselaer Polytechnic Institute | September 18, 2014 | Using Chemical Engineering to Solve Problems in Areas Least Expected

Distinguished Speaker Series

The successful CHBE Speaker Series attracts distinguished international speakers to come and give presentations on their research. More information, bios and abstracts are available on our website at www.chbe.ubc.ca.

January 20, 2014

DR. TONY MIKOS
Professor Bioengineering and Chemical and Biomolecular Engineering, Rice University
Biomaterials for Tissue Engineering

August 14, 2014

DR. G. D. YADAV
Vice-Chancellor and R. T. Mody Distinguished Professor, Institute of Chemical Technology, India
Selectivity engineering through novel catalyst design and development for valorization of glycerol

October 17, 2014

DR. NICHOLAS VON SOLMS
Professor, Technical University of Denmark
Do we want them or not? Gas hydrate inhibition and promotion in practice

November 4, 2014

DR. ROBERT BURRELL
Professor and Chair of Biomedical Engineering, University of Alberta
Nanomedicine: Advanced Nanostructured Materials

March 10, 2014

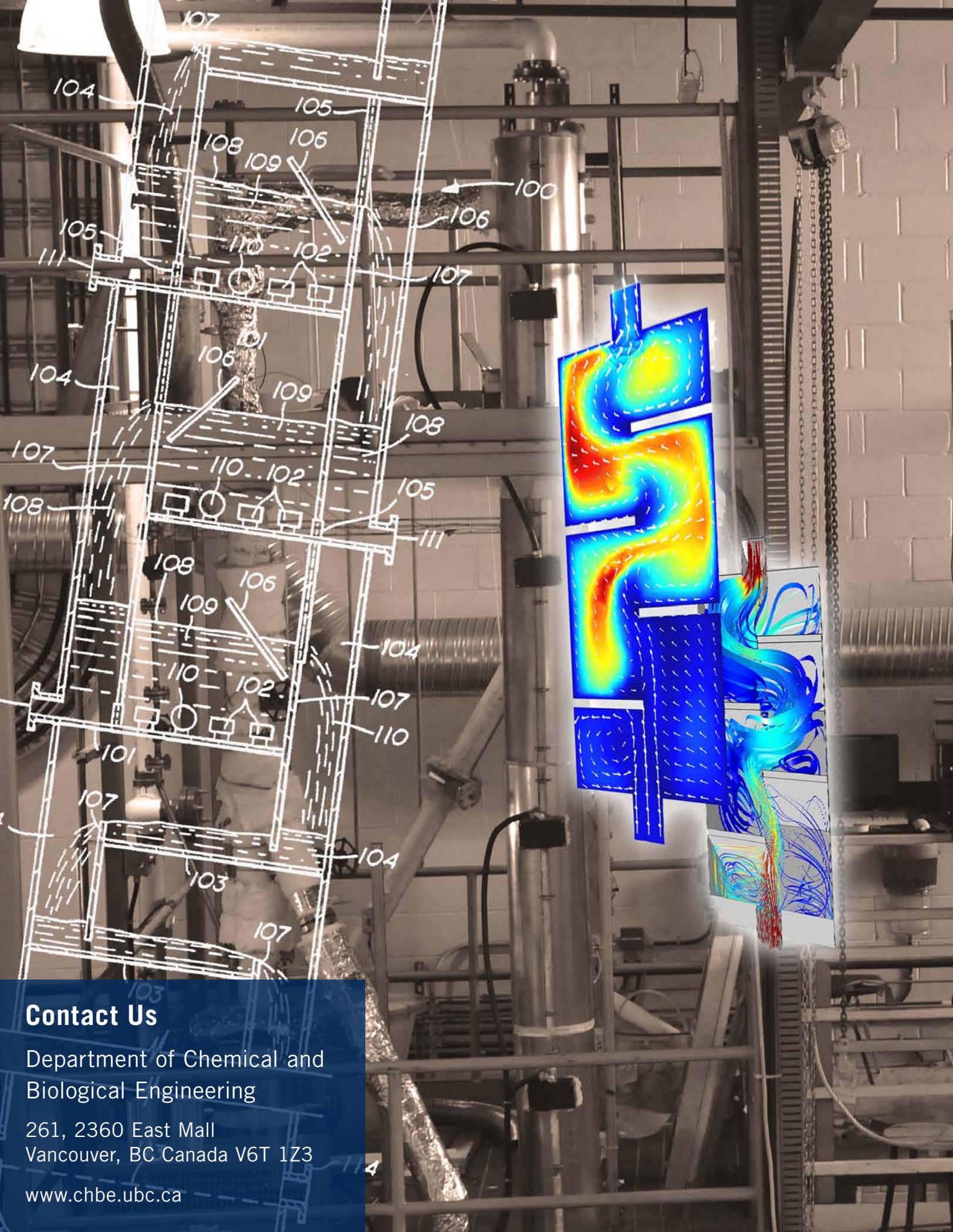
DR. SUSAN MULLER
Professor, Chemical & Biomolecular Engineering, University of California, Berkeley
Microfluidic tools for the manipulation and analysis of molecules, vesicles, capsules, and suspensions

September 30, 2014

DR. SCOTT RENNECKAR
Associate Professor, Department of Wood Science, UBC
Glycerol Thermal Processing of Biomass for Value-added Biomaterial

October 7, 2014

DR. LARRY BIEGLER
Chemical Engineering Department, Carnegie Mellon University
Nonlinear Programming Frameworks for Real-time Dynamic Optimization



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